Stratospheric-Tropospheric Exchange Events Observed by LASE In Tropics, Mid- and High-Latitude Regions

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ABSTRACT

Water vapor distributions, as measured by the Lidar Atmospheric Sensing Experiment (LASE), are shown to be a reliable indicator of stratospheric-tropospheric exchange events. LASE has participated in several atmospheric experiments where tropopause folds were observed via the water vapor field and confirmed by collaborating measurements. Data on these intrusions are presented from a variety of geographical regions, seasons and meteorological conditions. The water vapor field appears to be affected by the fold signatures to a deeper altitude, and with finer structure, than is apparent in the potential vorticity (PV) data typically used to indicate stratospheric intrusions into the troposphere.

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1. Introduction

Tropopause folds are associated with regions of tropopause height discontinuities [1]. These events lead to stratospheric-tropospheric mass exchange and are an important source of tropospheric ozone [2]. The first airborne lidar measurements of tropopause folds were reported by Browell, et al (1985) and these measurements of ozone and aerosols were made using the NASA airborne UV DIAL system in a tropopause fold study over the southwestern United States in 1984 [3]. The influence of tropopause folds on lower stratospheric moisture has also been discussed in the literature [4]. A tropopause fold event has also been observed using a water vapor DIAL system onboard the DLR Falcon aircraft [5].

NASA Langley Research Center's LASE (Lidar Atmospheric Sensing Experiment) system measures profiles of high resolution water vapor, aerosol and cloud distributions from various airborne platforms. LASE observed tropopause fold events via water vapor distributions during the TARFOX (Tropospheric Aerosol Radiative Forcing Observational eXperiment, July 1996, Eastern USA), PEM-Tropics B (Pacific Exploratory Mission Tropics B, tropical pacific, spring 1999) and SOLVE (SAGE-III Ozone Loss and Validation Experiment, Arctic, winter 1999-2000) field experiments. LASE has demonstrated the ability to detect tropopause folds over a variety of locations, seasons and meteorological situations onboard ER-2 and DC-8 aircraft and we report these results in this paper.

2. LASE System

LASE is an airborne lidar instrument which uses the DIAL (DIfferential Absorption Lidar) technique for the measurement of high resolution, atmospheric water vapor and aerosol profiles [6,7]. This system uses a double-pulsed Ti:Sapphire laser, pumped by a frequency-doubled Nd:YAG laser, to transmit light in the 815 nm absorption band of water vapor. LASE operates by locking to a strong water vapor absorption line and electronically tuning the frequency to a spectral position on the absorption line to optimize the absorption cross-section measurements over a range of water vapor concentrations in the atmosphere. When flown on the ER-2, such as in TARFOX, LASE operated in the nadir (down-looking) mode only, and alternated between strong (center of absorption cross-section) and weak (side of strong line) water vapor cross sections for the on-line DIAL wavelength in order to measure water vapor throughout the troposphere. For operations from the DC-8 (PEM-Tropics B and SOLVE), LASE was reconfigured to operate using strong and weak lines in nadir and zenith (up-looking) modes, thereby simultaneously acquiring data below and above the aircraft.

The typical water vapor data resolutions are 3 minutes (or 70 km) horizontally and vertically ~500 meters. Based on comparisons with other water vapor instruments, the measurement accuracy is 6% or 0.01 g/kg, whichever is larger [8].

In addition to measuring water vapor mixing ratio profiles, LASE simultaneously measures aerosol backscatter profiles at the off-line wavelength near 815 nm. Profiles of total scattering ratio are determined by normalizing the measured scattering (in a region containing enhanced aerosol scattering) to the expected scattering (of the "clean" atmosphere) at that altitude. The total scattering ratio is defined as the ratio of total (aerosol + molecular) scattering to molecular scattering. These aerosol profiles typically have horizontal and vertical resolutions of 200m and 30m, respectively.

3. LASE measurements

During the TARFOX flight occurring on July 26, 1996, LASE acquired data onboard the ER-2 as it flew from the Wallops Flight Facility to Bermuda. The water vapor field showed a tropopause fold at ~35 degrees N Latitude, 69 degrees W Longitude. The fold event occurred as the tropopause dropped from above 14 km to below 8 km. This is evidenced by the height of the cirrus clouds, which were at 15 km to the south and 9km to the north of the fold (figure 1). There is a marked change in the water vapor across the fold as shown in the time series plot taken at 9.5 km (figure 2). The LASE system demonstrated a sensitive capability for measuring water vapor in the upper troposphere and for observing tropopause folds at mid-latitudes.

LASE participated in the GTE, PEM-Tropics B mission in which several stratospheric intrusions into the troposphere were observed by a variety of instruments. Signatures of tropopause folds were evident by in situ and remote measurements of ozone and water vapor during the April 10, 1999 flight of the DC-8 aircraft. Notice the feature of high water vapor and low ozone air at 22:00 UT (figure 3). Figure 4 shows remotely measured DIAL ozone and LASE water vapor with PV contour overlays. The intrusion (shown by the bend in the PV contour lines in figure 4) can be seen in both the water vapor and ozone distributions, and they correlate very well with the PV data fields. There is an obvious anti-correlation between water vapor and ozone, as well as between water vapor and PV values. Figure 5 shows the relative profiles of the parameters across the intrusion at the above 8km.

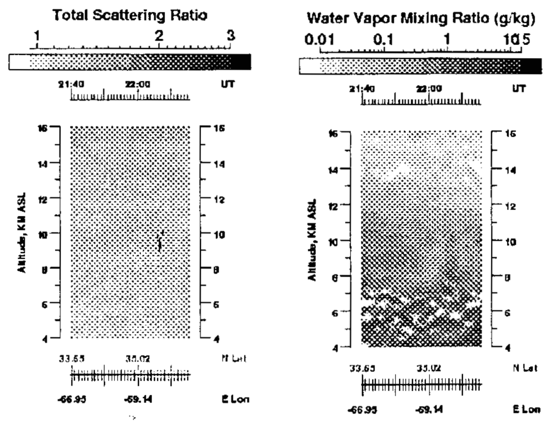

Figure 1: TARFOX flight 9 7/26/96 - LASE aerosol and water vapor fields showing strat-trop exchange

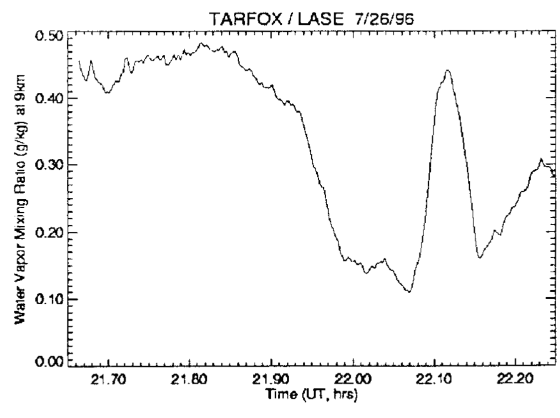

Figure 2: TARFOX / LASE average water vapor mixing ratios at 9km altitude, flight 9 7/26/96

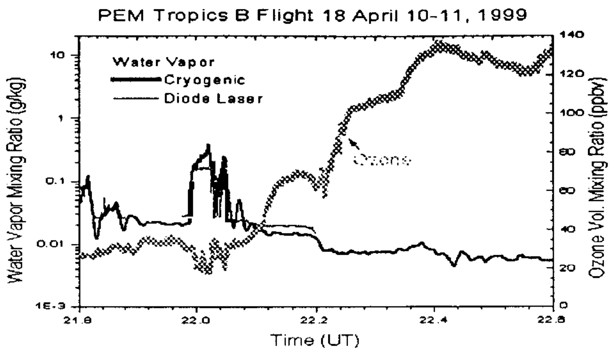

Figure 3: PEM-Tropics B in situ ozone and water vapor mixing ratios, flight 18 4/10/99

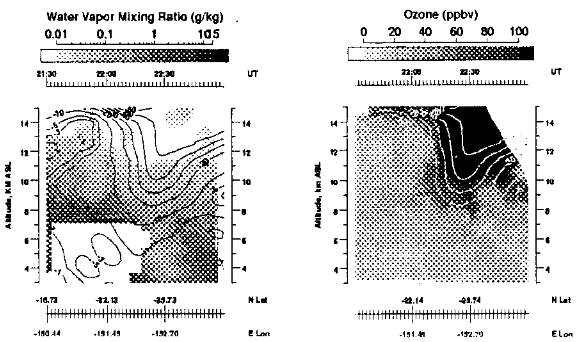

Figure 4: PEM-Tropics / LASE water vapor and UV-DIAL ozone fields, flight 18, 4/10/99, showing strat-trop exchange with PV contour overlays

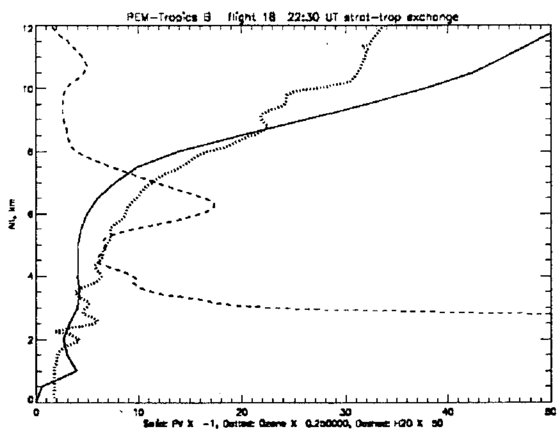

Figure 5: PEM-Tropics flight 18, vertical profiles of LASE water vapor (dashed), DIAL ozone (dotted) and PV (solid) during a strat-trop exchange event

LASE water vapor measurements provide high-resolution information that can be used to refine the lower resolution PV analysis. During the SOLVE campaign on December 5, 2000, LASE observed an extensive stratospheric-tropospheric exchange event while crossing the polar jet stream. Preliminary SOLVE water vapor mixing ratios were converted to relative humidity using temperature profiles provided by the DC-8 Microwave Temperature Profiler (MTP). The MTP instrument is a microwave radiometer that measures thermal emission from oxygen molecules at several elevation angles [9]. Relative humidity values (figure 6) illustrate the event more clearly than mixing ratios (figure 7), but caution is suggested since humidity is not a conservative tracer. There were many other observations of exchange during the SOLVE mission (January - March 2000) which are yet to be analyzed. LASE has proven to be a good tool for tropopause fold analysis, with more sensitivity to stratospheric intrusions at mid to high latitudes than in tropical regions.

4. Conclusions

Stratosphere-troposphere exchange can be observed and identified from LASE water vapor measurements. Relative humidity can be used to enhance the detection of intrusions under some conditions, but water vapor mixing ratio is a more conservative tracer. Intrusion events (identified by water vapor fields) appear more prominent at mid- and high-latitude regions than in the tropics. In regions of these exchanges, water vapor profiles are anti-correlated with ozone and potential vorticity (PV) fields. The signature of these appears to reach deeper into the troposphere than generally seen in the analysis, and the fine structure seen in water vapor data is not as evident in the PV fields. The location and extent of the intrusions can be quantified from LASE data. The influence of these events on troposphere-stratosphere exchange will be the subject of a future investigation.

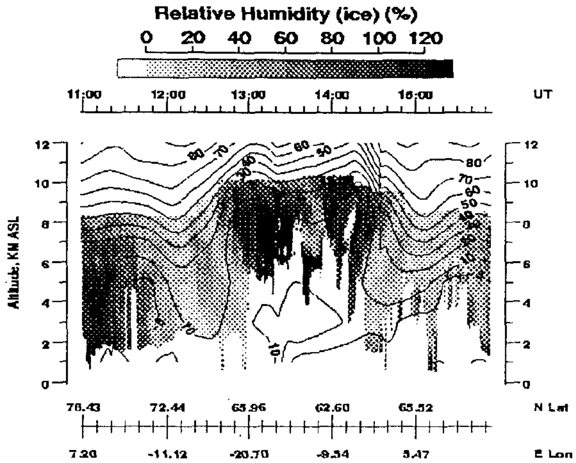

Figure 6: LASE relative humidity field during strat-trop exchange, SOLVE flight 8, 12/5/99

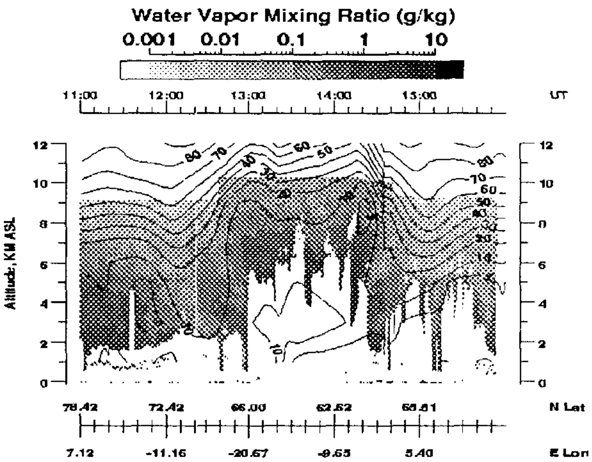

Figure 7: LASE water vapor mixing ratio field during strat-trop exchange, SOLVE flight 8, 12/5/99

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